Miscellaneous Paper ITL-95-2
June 1995

US Army Corps of Engineers
Waterways Experiment Station

A Literature Review of the Application of Knowledge-Based Systems to the Structural Design Process

by Ernest E. Morrison, Jr.

Prepared for Headquarters, U.S. Army Corps of Engineers

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Unannounced	☐	
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Dist	Avail and / or Special	
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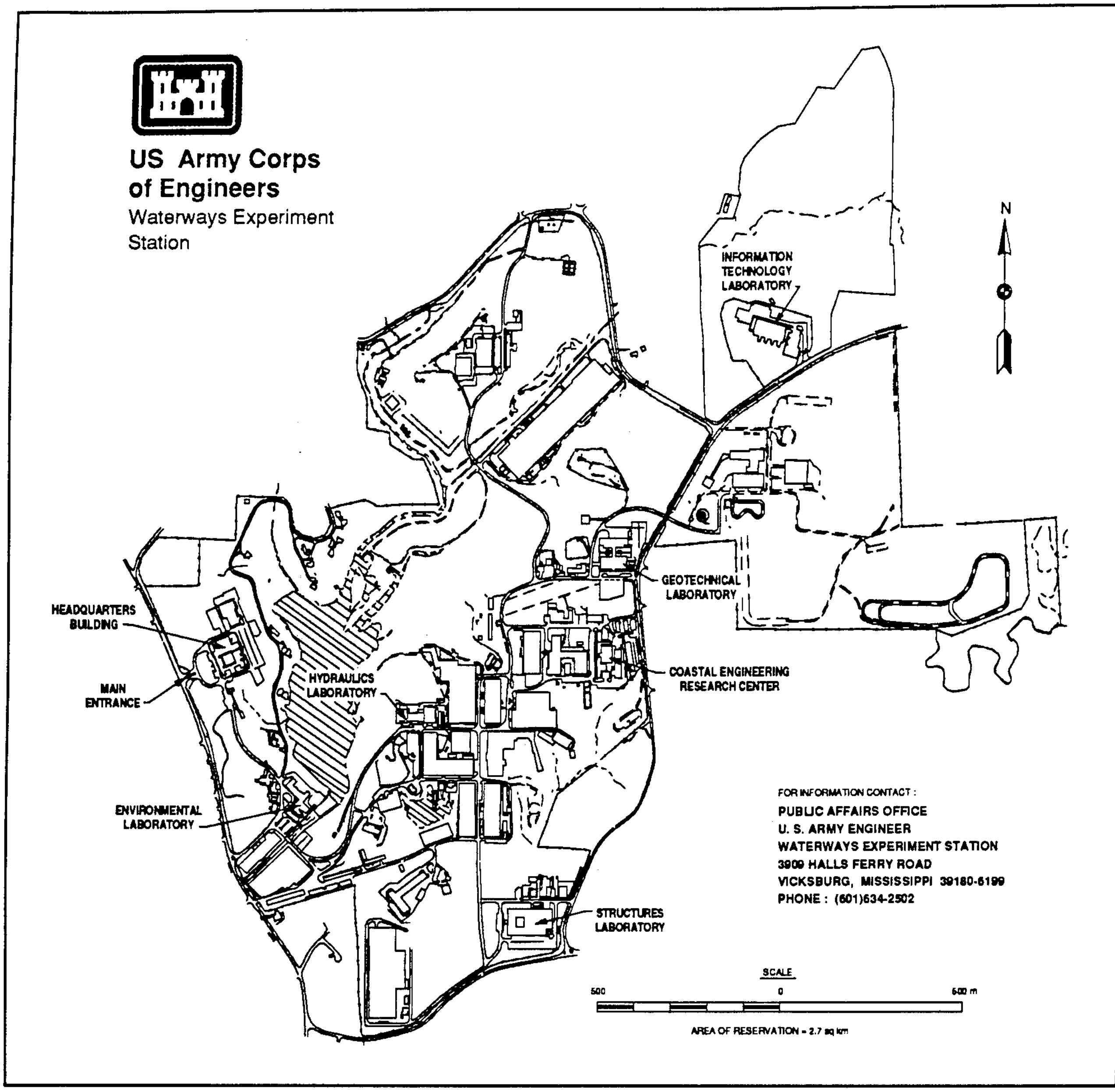
Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Morrison, Ernest E.
A literature review of the application of knowledge-based systems to the structural design process / by Ernest E. Morrison, Jr. ; prepared for U.S. Army Corps of Engineers.
20 p. : ill. ; 28 cm. -- (Miscellaneous paper ; ITL-95-2)
Includes bibliographic references.
1. Expert systems (Computer science) 2. Structural design. 3. Cost accounting. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Information Technology Laboratory (U.S. Army Engineer Waterways Experiment Station) IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; ITL-95-2.
TA7 W34m no.ITL-95-2

Contents

Preface

This report describes a literature review conducted as part of the work unit, "Intelligent Structural Design and Cost Estimating Technologies," Work Unit No. AT40-CA-002. Funds for the development and publication for this paper were provided to the Information Technology Laboratory (ITL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, by the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers, under the Research, Development, Test, and Evaluation program.

The work was performed by the Computer-Aided Engineering Division (CAED) of ITL. The investigation was accomplished under the general supervision of Dr. N. Radhakrishnan, Director, ITL, and under the direct supervision of Mr. H. Wayne Jones, Chief, CAED. This report was prepared by Mr. Ernest E. Morrison, Jr., CAED.

Dr. Robert W. Whalin was Director of WES during preparation of this report. COL Bruce K. Howard, EN, was Commander of WES.

1 Introduction

Background and Objectives

The research presented in this report was accomplished as part of the military direct project, Intelligent Structural Design and Cost Estimating (ISDCE).

The overall objective of the ISDCE project is to develop a computer program to provide a generic link between a typical building structural design computer program and the MCACES (Microcomputer Construction and Cost Engineering System) cost estimating computer program. The potential of knowledge-based systems (KBS's) to institute the generic link is to be explored. The linking program hopefully will permit design engineers to perform preliminary cost estimates quicker and at less cost than current manual methods.

This report has two major objectives: summarize the results of a literature review to determine the application of KBS's to the structural design process, and present general recommendations for the development of integrated structural design computer programs.

Limitations

It should be noted that the literature review reported herein is not comprehensive and was condensed to include only research relevant to the ISDCE project.

2 Description of Study

Literature Review

The objective of the literature review was to investigate the application of KBS's in the fields of structural engineering and cost estimating.

A surprising amount of research was found concerning improving the efficiency of the structural design process by utilizing knowledge-based computer programs. (For purposes of this report, the terms "structural design" and "construction industry" will include every process from architectural planning to final construction.)

The construction industry involves cooperation and coordination among many diverse professionals, including architects, engineers (civil, planning, and structural), structural detailers, contractors, and government officials. This type of project structure may therefore be considered distributed since these individuals represent different organizations. The current method of transferring data among individuals within this distributed project organization has been via plans and specifications.

A large number of computer programs exist to assist the structural designer, but many aspects of the construction project structure have not been computerized. The reviewed literature included efforts from the integration of computer programs to the automation of the entire structural design process.

The following sections briefly introduce research relevant to the development of comprehensive structural design systems. After this introduction, the implications of the research on future computer program development will be discussed.

Data usage

Fenves and Rasdorf (1982) felt the unifying element of a comprehensive design system would be a central database containing up-to-date information about the evolving design.

They described the typical usage of data as being in one of three categories:

a. *Temporary files.* Information (typically in some proprietary and/or binary format) is stored in temporary files for backup, restart, or postprocessing purposes.

b. *Explicit interface programs.* Explicit interface programs are written when the output of one program serves as input to another program.

c. *Text files.* Input and/or output data are saved in formatted text files. Input files can be edited and output files can be scanned for relevant information.

Fenves and Rasdorf (1982) went on to list three major shortcomings of the above three data storage and access methods:

a. The methods do not support flexible design methods where multiple programs may interact and multiple alternative designs may have to be executed and results compared.

b. All queries for data or updates to the stored data must be specifically programmed, using the internal representation of the data.

c. There are no general ways of ensuring or monitoring the integrity and consistency of the stored data. The user must know exactly where and in what format each piece of data is stored in each program to impose constraints on that data.

The last two of the above three shortcomings may be easier to understand by considering some simple examples.

In the second shortcoming, consider the case where the data to be accessed is stored in a data file using a proprietary binary format. (For example, the Corps of Engineers' preliminary structural design program, CASM (Computer-Aided Structural Modeling), stores data in a proprietary binary format.) Another program will be unable to access that data directly, hence explicit interface programs must be written. Consider the case of a structural engineer using a design program (CASM) and a computer-aided drafting (CAD) program (AUTOCAD), each storing data in a proprietary binary format. The programmer wishing to access data stored by CASM must be able to locate where and how the data is stored, essentially deciphering a binary data format. This task can be extremely difficult if the data format is not documented and the source code for the application is not available.

In the third shortcoming, consider the structural engineer who is using three computer programs (e.g., a design program, a CAD program, and a cost estimating program), each of which stores data in a proprietary binary data format. In this example, data concerning the size of a steel beam may be stored in three separate data files, and in three separate binary data formats. To maintain data integrity, modifying the depth of a beam would

require updates to three separate binary data files. One way to allow flexible design sequences and provide for data consistency would be to write a data integrity maintenance program to ensure that updates are made to all three data files. This method is illustrated in Figure 1. The explicit interface programs would be difficult to create due to the proprietary nature of the program data files. The data integrity maintenance program would be complex due to the need to track data in three separate programs. Further, this system of programs becomes unusable if any one of the three proprietary data formats is modified.

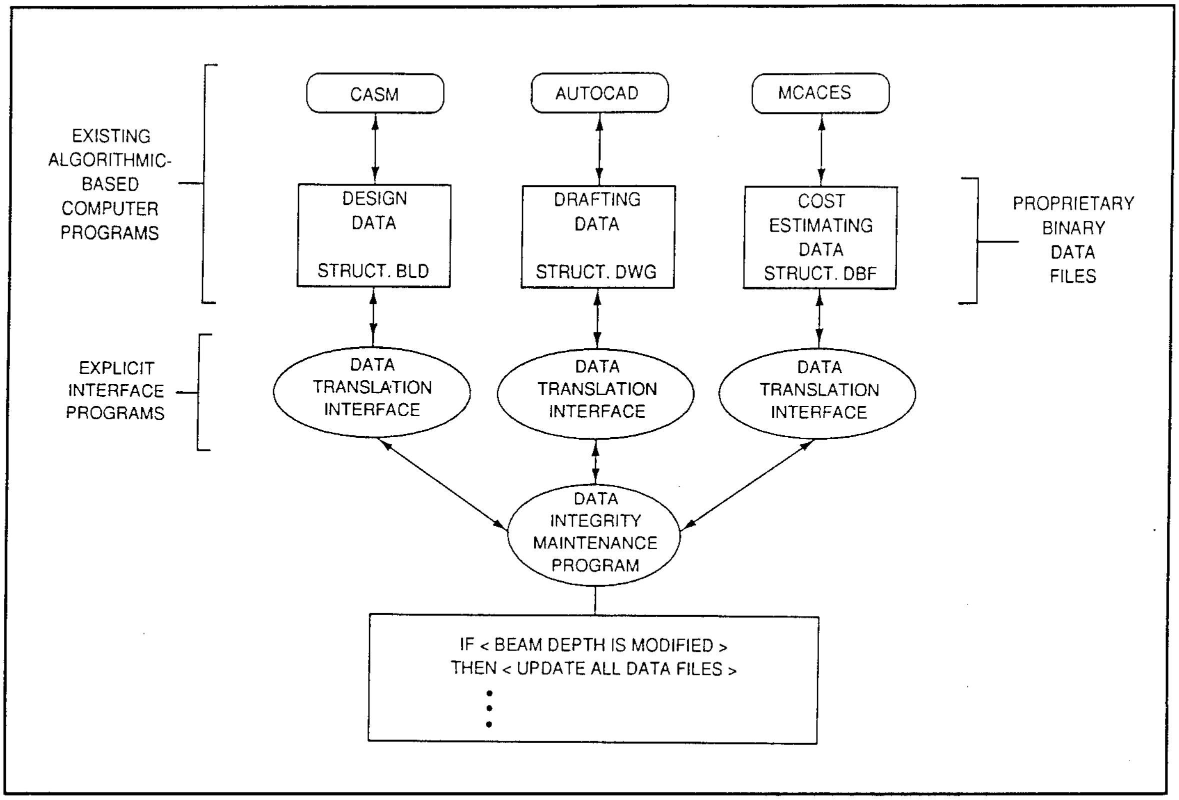


Figure 1. A design system utilizing algorithmic programs and explicit interface programs

Fenves and Rasdorf (1982) stated that data exchanged and shared among the applications is the key to program integration. One of three options may be selected by an organization desiring a comprehensive structural design system:

a. Extend the present mode of high program-data dependence (e.g., construction of explicit interface programs, etc.).

b. Wait for the development of the "ideal" integrated design system, incorporating all structural engineering functions.

c. Utilize a database management system (DBMS) as a centralized storage area for the structural design data. (A DBMS is created to store data such that many different applications, both existing and

planned, utilize a common data source. The data must be structured for efficient use, but not tailored to a specific application program.)

Fenves and Rasdorf (1982) recommended extensions to the relational DBMS model to achieve the desired integration of applications both horizontally (among different structural applications) and vertically (between structural applications and the applications of other disciplines).

Knowledge-based architecture for integrated structural engineering applications

Rehak, Howard, and Sriram (1985) stated that work on producing an integrated design environment for structural engineering has been ongoing for two decades. Systems such as ICES (Roos 1966), GENESYS (Genesys Limited 1976), and POLO (Lopez 1972) were cited as examples.

Rehak, Howard, and Sriram (1985) stated that in the late seventies, researchers realized the algorithmic approach was not adequate to develop an integrated structural engineering design environment. Fenves (1981) stated that computer use in structural engineering was extensive, but limited to algorithmic-based programs, which are capable of assisting the engineer in a small portion of the total design process. Ill-structured problems, standards processing, and the fragmentary nature of the construction industry often cannot be directly addressed using algorithmic programming techniques. Researchers identified knowledge-based expert systems as being potentially useful to address the ill-structured and creative aspects of the design process. Centralized database management was identified as a potential tool for linking the various design applications into an integrated system.

Rehak and Lopez (1981) reported a conceptual architecture for an integrated civil engineering design environment (CAESE, Computer-Aided Engineering and Software Environment). These researchers reported continuing work to progressively extend and revise the concept, and to construct prototype knowledge-based components.

Rehak, Howard, and Sriram (1985) reviewed the prototype knowledge-based components developed to date, and described a basic plan for integrating the components into a working design system. The reader is referred to this reference for further details.

The above reference is somewhat dated, but of interest for the following reasons:

a. Discusses the long-term interest in developing integrated structural design systems.

b. Describes the early realization that computer-program-based algorithmic methods alone cannot address the creative and ill-structured aspects of structural design and the construction process.

c. Illustrates the need to plan for the development, data storage, and control of the components to be used in any proposed integrated structural design system.

KADBASE—Interfacing expert systems with databases

Howard and Rehak (1989) stated that integrated engineering computer systems had evolved into sets of algorithmic programs revolving around a central DBMS.

Howard and Rehak reported their knowledge-aided database management system prototype KADBASE. This working prototype was described as a flexible, networked database interface in which multiple databases and knowledge-based systems can communicate as independent, self-descriptive components within an integrated computer-aided engineering system.

KADBASE has the following features:

a. It separately stores descriptive knowledge about processing data requests from each component of the system.

b. Each expert system or database is linked only to the interface.

c. Multiple DBMS networks integrate information from individual engineering databases into a single global semantic database model.

d. The distributed nature of KADBASE's architecture is hidden from users and applications.

The advantages of a system such as KADBASE are as follows:

a. By storing descriptive knowledge (feature *a*) a more flexible interface is developed versus that provided by purely algorithmic linkages. This additional flexibility is typically needed to support the more diverse data access needs of expert systems and engineering databases.

b. By linking components only to the interface (feature *b*), new expert systems and DBMS's can be easily added to the system. Further, each component may be implemented as a separate process.

c. Features *c* and *d* allow the flexibility of each component coexisting on a single machine, or distributed to multiple machines.

Howard and Rehak (1989) described KADBASE and two knowledge-based structural engineering applications:

a. HICOST, a knowledge-based cost estimator for detailed building designs.

b. SPEX (Garrett 1986), a knowledge-based, standard independent, structural component design system.

Howard and Rehak (1989) stated HICOST and SPEX were successfully integrated into the KADBASE environment. They felt that since SPEX was an independently developed component, the successful integration was evidence that the basic concepts were valid.

KADBASE and the above described applications were implemented on a VAX 11/750 and several MicroVAX's connected via a local area network (LAN). The operating system was Mach (a version of UNIX). Franz Lisp was the primary programming language with the INGRES DBMS supporting the sample databases. The KADBASE environment is illustrated in Figure 2.

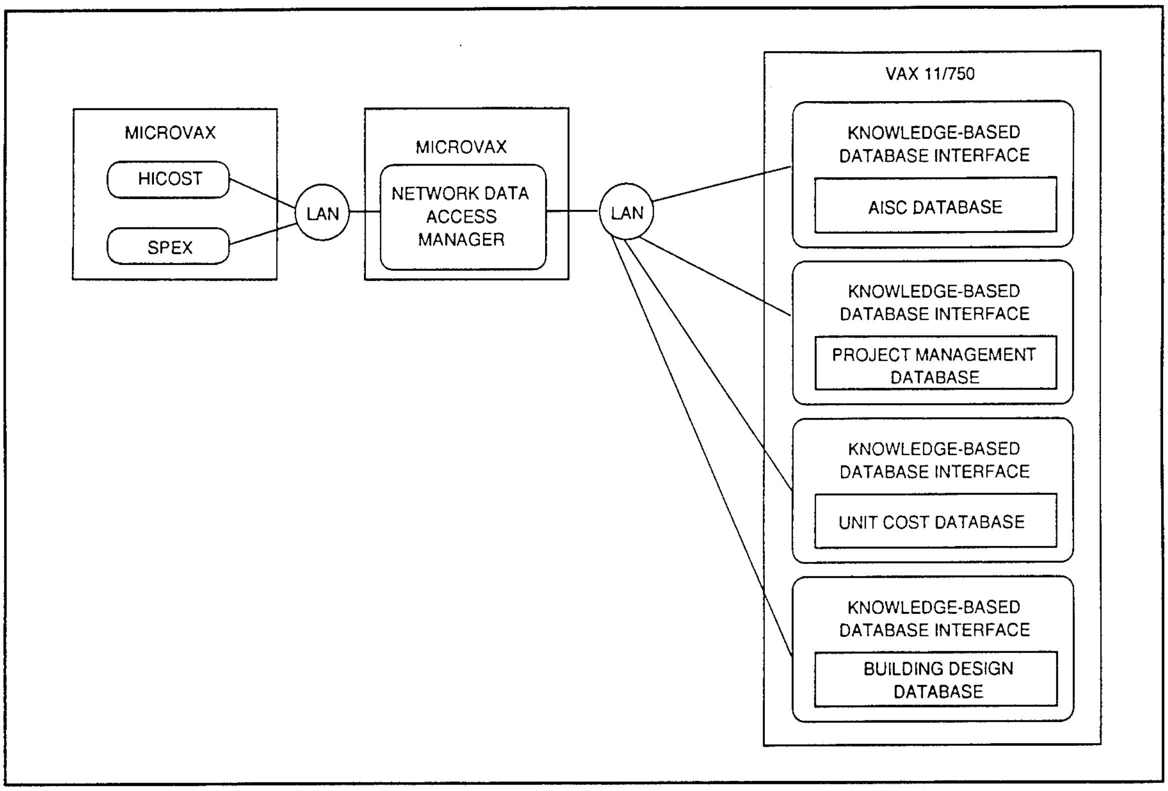


Figure 2. The distributed KADBASE environment (after Howard and Rehak 1989)

Howard and Rehak (1989) stated KADBASE provides a working model for the development of an integrated data space. They foresee a single integrated structural engineering environment which will include multiple knowledge-based design tools, analysis routines, user interfaces, and databases supported on networked processors.

DICE—Distributed and integrated environment for computer-aided engineering

Sriram et al. (1989) reported a system architecture described as a distributed and integrated environment for computer-aided engineering (DICE). This architecture is intended to provide for the integration and coordination of various phases and participants in the engineering of a product.

The objectives of DICE were described by Sriram et al. (1989) as follows:

a. Facilitate effective coordination and communication in various disciplines involved in engineering.

b. Capture the process by which individual designers make decisions, that is, what information was used, how it was used, and what the information created.

c. Forecast the impact of design decisions on manufacturing or construction.

d. Provide designers interactively with a detailed manufacturing process or construction planning.

e. Develop intelligent interfaces for automation.

Sriram et al. (1989) described five computer-based software development tools utilized to develop DICE: object-oriented programming, knowledge-based systems, database management systems, visual computing, and local area networks.

DICE is described as a network of computers and users with coordination and control via a control mechanism acting on a global database. The three basic components of DICE are:

a. Control mechanism, controls the communication, coordination, and data transfer functions.

b. Blackboard, the medium through which communication occurs, functioning as an intelligent database. It is subdivided into three partitions, coordination, solution, and negotiation. Data from different computer programs may be stored on the blackboard and passed to other programs as needed.

c. Knowledge modules, which can be either a knowledge-based expert system, an algorithmic program, or a CAD tool.

Sriram et al. (1989) selected the Hyatt Regency disaster (Marshall et al. 1982) as a test case. They illustrated their development environment by successfully modelling the Hyatt Regency walkway design process. The simulation took as input the original one rod connection design of the fourth floor walkway, and compared that with the structural fabricator's

connection design. The simulation notified the connection designer and the structural fabricator that the designs were incompatible. The simulation was developed on two SUN computers and completed in 1987.

Sriram et al. (1989) also reported that work is in progress to modify and integrate computer program BUILDER by Cherneff (1988) into the DICE environment. BUILDER automatically generates construction schedules from architectural drawings, and was developed in KEE . (KEE is a hybrid knowledge-based programming environment originally developed in LISP and capable of processing LISP functions; see Fikes and Kehler (1985) for details.) The modified version of BUILDER will be called DICEY-BUILDER and will be implemented to demonstrate communication between heterogeneous knowledge modules and to develop a protocol mechanism similar to the LAN model. The implementation details of this effort were described by Groleau (1989).

DICE is being implemented in a hybrid programming environment called PARMENIDES/FRULEKIT. PARMENIDES/FRULEKIT supports programming in frames and rules and was developed in LISP at Carnegie-Mellon University by Carbonell and Shell.

Sriram et al. (1989) described continuing efforts in the areas of constraint negotiation for resolving conflicts between various designers (e.g., interferences between mechanical equipment and structural members), a layered communication protocol to facilitate the communication between different disciplines, an X-window user interface, and secondary storage management facilities. They also proposed to demonstrate DICE in an industrial setting.

An integrated software environment for building design and construction

Fenves et al. (1988) introduced an integrated software environment for building design and construction (IBDE). The prototype system was developed to address the distributed project organization inherent in the construction industry (e.g., the construction industry involves cooperation and coordination between many diverse professionals, including architects, engineers (civil and structural), structural detailers, contractors, and government officials, to mention a few). Improved communication between the different organizations that participate in the planning, design, and construction of office buildings was a major goal of the prototype.

The IBDE acts to integrate the processes and information flows of architectural design, structural design and analysis, and construction planning. Fenves et al. (1989) suggested a computer-based replacement for the drawings and specifications which are the current media for communicating design decisions involving many different professionals. The IBDE also portends a paradigm shift of computer usage away from purely numeric calculations and towards symbolic reasoning.

The integrated environment addressed three aspects of the communication issues: representation of project information through the project life, communication of information among the computer based processes, and control of the process.

The IBDE design processes consists of five integrated knowledge-based modules:

a. ARCHPLAN, an architectural planning expert system which assists in developing the conceptual design of a building (Schmitt 1987).

b. HI-RISE, an expert system which performs the preliminary structural design of high rise buildings (Maher and Fenves 1984).

c. SPEX, a component designer for preliminary structural design (Garrett and Fenves 1986).

d. FOOTER, an expert system that performs a preliminary design of the foundation of a building (Maher and Longinos 1987).

e. CONSTRUCTION PLANEX, a knowledge-intensive expert system intended to assist the construction planner (Hendrickson et al. 1987).

The modules communicate with each other via a message blackboard, and a database is used to store the information generated and used by the modules. A controller uses information placed on the blackboard to control the execution of processes and directs the database manager to retrieve and store information. This program structure is illustrated in Figure 3.

The knowledge-based modules may physically reside on different machines, thus the database manager and the blackboard utilize a local area communications network. The control and communication are implemented on top of the DPSK (distributed problem solving kernel) system developed by Cardozo (1987). The DPSK allows distributed problem solving via programs written in multiple languages and involving multiple computers.

Fenves et al. (1988) considered their integrated environment to exhibit many of the features required for a new generation of computer tools. As of October 1987, the system was in the last phase of implementation, and they reported several complete designs had been generated.

Summary of Literature Review

As previously stated, a surprising amount of research was found related to improving the efficiency of the structural design process. The research presented in this report is not comprehensive, concentrating on that which is most directly applicable to the ISDCE project.

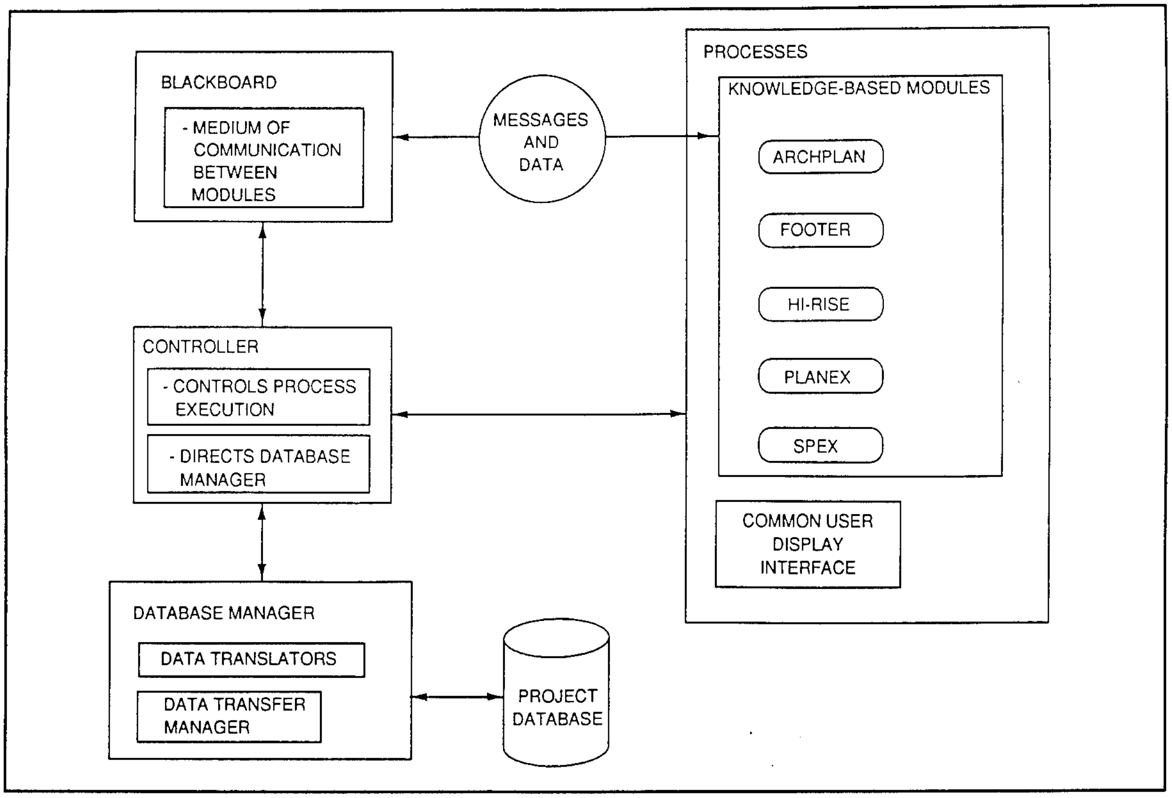


Figure 3. IBDE architecture (after Fenves et al. 1988)

Much of the previously presented research focused on efforts to utilize KBS's to simplify and automate the structural design process. According to many researchers, KBS's will supplant the current algorithmic-based approach to the development of structural design programs. Further, researchers are now attempting to virtually reinvent the way buildings are planned, designed, and constructed.

Fenves et al. (1988) suggested a knowledge-based replacement for the drawings and specifications which are the current media for communicating design decisions involving many different professionals. They described a system which has generated several complete designs.

Sriram et al. (1989) reported a system architecture described as a distributed and integrated environment for computer-aided engineering (DICE). This architecture is intended to provide for the integration and coordination of various phases and participants in the engineering of a product (or constructing a building). They illustrated their development environment by successfully modelling the Hyatt Regency walkway design process in a networked environment.

Howard and Rehak (1989) reported their knowledge-aided database management system prototype KADBASE. This working prototype was described as a flexible, networked database interface in which multiple da-

tabases and KBS's can communicate as independent, self-descriptive components within an integrated computer-aided engineering system.

The amount of research and the reported success of the knowledge-based approach suggests a paradigm shift in computer usage in the construction industry. Fenves et al. (1988) predicts that computer programs will shift from purely numeric calculations towards symbolic and knowledge-based reasoning.

3 Conclusions and Recommendations

The literature review has illustrated that integrated structural design systems are feasible. Detailed planning is required for the development of integrated design systems. Although the coordination and control mechanisms are currently under development, KBS's will probably form the core of future integrated design systems.

Clearly, solely algorithmic methods are now the limiting factor in improving the scope of computer usage in the construction industry. Stated another way, expanding current algorithmic-based programs and linking them via explicit interface programs will have limited utility. Further, limitations can be foreseen in the utilization of knowledge-based modules added to existing algorithmic programs. Neither technique can be utilized to develop the comprehensive structural design systems with the capabilities reported in the literature.

Implementation of comprehensive integrated systems will require careful top down planning. The design of an integrated system is more likely to be successful if the integration issues are addressed before the components are created. (Program control, coordination, and the development of a centralized database are common and critical issues discussed by the researchers.)

The current method of developing a specific algorithmic application and then attempting to connect that program to other independently developed algorithmic programs will hamper, if not defeat, efforts to develop integrated systems. Although Howard and Rehak (1989) reported the ability to integrate separately developed applications, each application was a knowledge-based system.

Research should be funded to decide how an integrated design system should be implemented. Such research can include both a more detailed study of the state of the art in this field, and a review of the results achieved by the above described projects. It would be desirable to visit the research facilities and perform a hands-on review. If the existing systems are sufficiently advanced, the Corps of Engineers should select the most promising

technology for either purchase, or independent development. Either action would start the Corps of Engineers on the path to developing integrated design systems.

References

Cardozo, E. (1987). "DPSK: A kernel for distributed problem solving," Technical Report EDRC-02-04-87, Engineering Design Research Center, Carnegie Mellon University, Pittsburgh, PA.

Cherneff, J. (1988). "Automatic generation of construction schedules from architectural drawings," unpublished M.S. thesis, Massachusetts Institute of Technology, Cambridge, MA.

Fenves, S. J. (1981). "Computer-aided design in civil engineering," *Proceedings of the IEEE* 69(10), 1240-1248.

Fenves, S. J., and Rasdorf, W. J. (1982). "Role of database management systems in structural engineering," Technical Report DRC-12-13-82, Design Research Center, Carnegie Mellon University, Pittsburgh, PA.

Fenves, S. J., Flemming, U., Hendrickson, A. M., Maher, M. L., and Schmitt, G. (1988). "An integrated software environment for building design and construction. " *Computing in civil engineering: Microcomputers to supercomputers*. K. M. Will, ed., American Society of Civil Engineers, New York, 21-32.

Fikes, R., and Kehler, T. (1985). "The role of frame-based representation in reasoning," *Communications of the ACM* 28(9), 904-920.

Garrett, J. H. (1986). "SPEX - A knowledge-based standards processor for structural component design," Ph.D. diss., Carnegie Mellon University, Pittsburgh, PA.

Garrett, Jr., J. H., and Fenves, S. J. (1986). "A knowledge-based standards processor for structural component design," Technical Report R-85-157, Department of Civil Engineering, Carnegie Mellon University, Pittsburgh, PA.

Genesys Limited (1976). "GENESYS," Technical Report, Genesys Limited, Loughborough, England.

Groleau, N. (1989). "A blackboard architecture for communication and coordination in design," unpublished M.S. thesis, Massachusetts Institute of Technology, Cambridge, MA.

Hendrickson, C. T., Zozaya-Gorostiza, C. A., Rehak, D., Baracco-Miller, E. G., and Lim, P. S. (1987). "An expert system for construction planning," *ASCE Journal of Computing in Civil Engineering* 1(4), 253-269.

Howard, H. C., and Rehak, D. R. (1989). "KADBASE: Interfacing expert systems with databases," *IEEE Expert* 4(3), 65-76.

Lopez, L. A. (1972). "POLO: Problem oriented language organizer," *Computers and Structures* 2(4), 555-572.

Maher, M. L., and Fenves, S. J. (1984). "HI-RISE: An expert system for the preliminary structural design of high rise buildings," Technical Report R-85-146, Department of Civil Engineering, Carnegie Mellon University, Pittsburgh, PA.

Maher, M. L., and Longinos, P. (1987). "Development of an expert system shell for engineering design," *International Journal of Applied Engineering Design*, Pergamon Press.

Marshall, R. D., et al. (1982). "Investigation of the Kansas City Hyatt Regency walkway collapse," Technical Report, Science Series 143, National Bureau of Standards, Washington, DC.

Rehak, D. R., and Lopez, L. A. (1981). "Computer aided engineering: Problems and prospects," Civil Engineering Systems Laboratory Research Series (CESLRS) 8, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL.

Rehak, D. R., Howard, H. C., and Sriram, D. (1985). "Architecture of an integrated knowledge-based environment for structural engineering applications. " *Knowledge engineering in computer-aided design*. J. S. Gero, ed., Elsevier Science Publishers, North-Holland, 89-123.

Roos, D. (1966). *ICES system design*. MIT Press, Cambridge, MA.

Schmitt, G. (1987). "ARCHPLAN - An architectural planning front end to engineering design expert systems," Technical Report, Engineering Design Research Center, Carnegie Mellon University, Pittsburgh, PA.

Sriram, D., Logcher, R. D., Groleau, N., and Cherneff, J. (1989). "DICE: An object oriented programming environment for cooperative engineering design," DAAL03-86-G-0197, Intelligent Engineering Systems Laboratory, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1995	Final report

4. TITLE AND SUBTITLE

A Literature Review of the Application of Knowledge-Based Systems to the Structural Design Process

5. FUNDING NUMBERS

6. AUTHOR(S)

Ernest E. Morrison, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

Miscellaneous Paper
ITL-95-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A large number of computer programs exist to assist the structural designer, but many aspects of the construction project structure have not been computerized. Further, problems with the transfer of data between existing computer applications hinder the development of integrated structural design systems. Researchers have stated that knowledge-based systems (KBS's) provide the key to the development of integrated structural design systems. To investigate this claim, a literature review concentrating on the application of KBS's to the structural design process was undertaken. This report has two major objectives: summarize the results of a literature review to determine the application of KBS's to the structural design process, and present general recommendations for the development of integrated structural design computer programs.

14. SUBJECT TERMS

Knowledge-based systems   Structural design

15. NUMBER OF PAGES 20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		